2.1.3 Test Engineering Documentation

There are three major items that Test Engineering generates during system development, a Test Engineering Management Plan (TEMP), a System Testability Requirements Document (STR), and a Test Plan. In addition, TE contributes to several other products that are the responsibilities of other disciplines. For example, System Requirements are the direct responsibility of the System Engineering discipline but are examined by TE for correctness. Correctness means that system requirements have been correctly interpreted and implemented and therefore can be tested. The products for which TE is directly responsible are:

- Test Engineering Management Plan (TEMP) - The purpose of the TEMP is to:
  - establish the TE approach and plan;
  - establish the system resources allocated to TE;
  - identify TE risks and problem areas (e.g., untestable requirements, design complexity, etc.) early in the life cycle.
- System Testability Requirements (STR) - The STR defines system and interface requirements imposed by TE for system testability.
- Test Plan - The Test Plan establishes the System Test and System Integration test approach, plan, design, and cases and procedures necessary to meet System Engineering's test requirements (acceptance criteria).

Additional information regarding the non test documents and specifications called for in D-5000 are discussed within the JPL System Development Management Guide. It also contains charts describing all development activities, but not to the level of detail found in this handbook.

2.1.4 Tailoring Products to Projects of Various Sizes

Each of the defined three basic TE products. can be condensed or expanded depending upon the size and needs of the project or task. For example:

- all discipline management plans, including the TEMP, could be combined for a small scale task;
- all three TE products could be combined into a single document;
- all components of a Test Plan (e.g., the System Integration Test Plan (SITP) and the System Test Plan (STP)) could be combined into a single document;
- all TE products could be individual documents and could even have multiple Test Plan volumes, for a large scale project (eg., one for the spacecraft and another for ground data).

NOTE

D-5000 specifies the types of information needed by a test effort, but does not impose any constraints upon how information is assembled. Packaging of products is determined by a particular project or task.

2.2 Planning Phase

OBJECTIVES

1. Provide fundamental technical assumptions on test design and implementation for cost and management planning.
2. Develop strawman requirements and design for test support and facilities.

ACTIONS

1. Prepare Test Engineering Management Plan.
   - Establish test approach.
   - Assemble and analyze Test Requirements (e.g., facilities, hardware, software, etc.).
   - Identify test tool needs.
2. Begin formulation of Test Plan

Support Activities:

1. Support analysis and development of management plans and requirements.
2. Define TE metrics and begin data collection.
3. Conduct TE Trade Study.
4. Collect data for Lessons Learned

REVIEW

1. Has a general test strategy been established?
2. Have the test-effort requirements been specified?
3. Are the TE resources allocated commensurate with planned activities?
4. Have metrics been defined and data collection begun?
5. Is a TE trade study being conducted?
6. Are data for Lessons Learned being collected?

RECEIVABLES

at the start of or during the phase

SDS Data Items:

Management Plans
- Documentation Plan
- Configuration Management Plan

Other:

Preproject plans, assumptions, and constraints

DELIVERABLES

TE SDS Data Items:

Emphasis during phase

Test Engineering Management Plan

Initial approaches and assumptions

System Testability Requirements
Test Plan

TE Reports:

Metrics Report
Lessons Learned
Trade Studies

METRICS

1. Cost to discover anomalies during each phase versus the cost to find the anomalies later in the development life cycle. This is an indicator of cost savings due to early involvement of TE.
2. Cost of TE documentation versus total test cost. This is an indicator of the value of time and money spent on adequate test documentation.

Figure 5. Planning Phase-Action Chart

2.2.1 Planning-Phase Objectives

The TE Planning Phase objective (see Figure 5) is to establish an overall test philosophy and plan adequate to support a task or project. Using available inputs, such as preliminary system requirements, project requirements, and available resources, a general test strategy is developed. This strategy provides a basis for subsequent test activities. A primary goal of this early planning is to determine whether allocated test resources are commensurate with required activities.

TE should begin to ensure that early evolving System Requirements are both "testable" and "able to be tested." These two concepts are important. There is a significant difference in meaning between "testable" and "able to be tested." "Testable" refers to a requirement that is stated in a measurable manner. Subjective requirements such as, "The system shall improve service to users" is an ambiguous and unmeasurable objective, while a statement that, "The system shall process a user request in four minutes" is measurable. A requirement that is "able to be tested" is one that can be physically and/or economically tested (e.g., a spacecraft larger than an environmental simulator is physically impossible to test, and it may not be economically feasible to construct a larger simulator).

2.2.2 Planning-Phase Actions

Planning-phase activities consist of:

- developing a TEMP;
- formulating an early Test Plan;
- examining the early system and project requirements;
- developing a trade study (if required);
- collecting TE metrics.

TE concerns to consider in the TEMP during the Planning Phase are:

- test requirements levied on facilities, hardware, procedures, and software to ensure a testable system;
- constraints levied by outside agencies (i.e. Goddard Space Flight Center, European Space Agency, Department of Defence, etc.) or due to payload classification (i.e., payload classes A, B, C, or D);

- allocation of test resources such as budget and staffing to meet test requirements;
- test tools necessary for a cost-effective program;
- Configuration Management processes for sufficient control of test activities and products;
- test schedules to define activity flows;
- definition of metrics to measure test activities and products.

Early formulation of a Test Plan using available information begins in this phase. The early involvement of TE assists in the understanding and analysis of preliminary requirements. Once a test approach and plan is developed, it is updated throughout the life cycle to reflect changes and results of negotiations between management and other disciplines. Furthermore, other discipline data items, such as a System Engineering Management Plan, should be reviewed by TE to ensure compatibility with TE. If conflicts arise, negotiations between Project Management, TE, and other involved disciplines take place and resolution documented.

Preliminary system and project requirements are used for the early test strategy and planning. However, if these preliminary requirements are not available, documented assumptions are made. Subsequent testing activities are based on System Requirements that evolve from these preliminary assumptions. The goal is to define a Test Plan that responds to these requirements and is based on resources allocated for the test process; if the resources allocated are insufficient or not adequately defined, then negations with system management to correct the problem are needed.

TE metrics for the phase, as defined in the TEMP are collected and reported. A Test Engineering Trade Study Report (if required), documenting different test strategies or techniques and respective costs, is started.

2.2.3 Planning-Phase Receivables

Preliminary system requirements, constraints, and resources should be adequately defined for planning to occur. Great detail is not necessary, but agreement between management and other disciplines is crucial. If requirements, constraints, or resources are not available, assumptions are made and documented in the TEMP.

Management Plans

Management Plans are received from other disciplines. They define:

- how System Management is to be defined;
- how development resources are to be utilized;
- what subsystem development processes are defined and what requirements they must meet;
- what resources are available for subsystem development.

Detailed Phase Plan

The Detailed Phase Plan is delivered by System Management, during the phase and updated at the end of each phase. The Detailed Phase Plan is intended to establish readiness to begin the phase. More importantly, it also provides detailed schedules and precedence charts for intraphase products and actions between disciplines. Since there is no previous phase prior to the Planning Phase, the document is prepared preproject by the System Manager.

2.2.4 Planning-Phase Deliverables

Test Engineering Management Plan (TEMP)

The TEMP (see Appendix B) documenting test management and strategy is baselined at phase end. The TEMP establishes the TE approach and plan to:

- meet test responsibilities and effectively use resources allocated to TE;
- reduce testing problems by involving TE early in the life cycle;
- begin analysis of preproject requirements;
- document any constraints or acceptance criteria that may have been imposed (e.g., Data Requirements Description (DRD), Contract Data Requirements List (CDRL), or different payload classes).

Figure 6 shows the essential content of a TEMP.

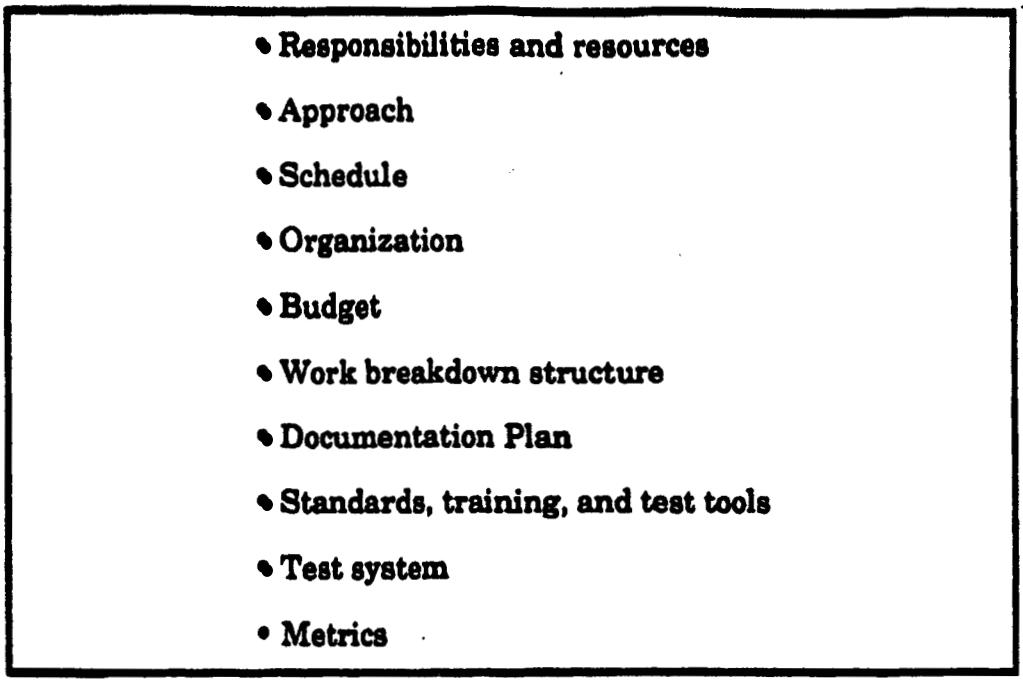

Figure 6. TEMP Essential Contents

Trade Study

A Trade Study (if required) is started to examine different test strategies or techniques that may be applied and the cost related to using each proposed strategy. The Trade Study task is carried out during the first four life-cycle phases, so strategies and techniques commensurate with resources allocated for testing can be determined. This study may also result in justification for additional resources.

Metrics Report

A Metrics Report containing the first test metrics collected during the life cycle is prepared. This report also includes comparisons between previous project metrics with current project metrics in order to assess test activities.

2.2.5 Planning-Phase Metrics

Some typical metrics are:

- cost to discover anomalies during each phase versus cost to find anomalies later in the development life cycle. This is an indicator of cost savings due to early involvement of TE.

- cost of TE documentation versus total test cost. This is an indicator of the value of time and money spent on adequate test documentation.

2.2.6 Planning-Phase Review Criteria

Review criteria for a phase are in the form of a checklist to help TE and System Management determine if test-management planning activities have been completed. The review criteria during the Planning Phase are to ensure that:

- test strategy and approach have been established;
- all plans have been examined to determine if facilities needed to support test are adequately addressed;
- all the TE management issues are addressed in a TEMP that is baselined at phase end;
- resources allocated by system management for testing are commensurate with planned activities.

2.3 Requirements Phase

OBJECTIVES

1. Provide test design assumptions to support test requirements analysis.
2. Propose and justify requirements on the system to achieve cost-effective test.

RECEIVABLES

at the start of or during the phase

SDS Data Items:

1. System Requirements
2. Integration & Test Requirements
3. Installation Test Requirements
4. Operational Certification Requirements
5. Detailed Phase Plan
6. Updates to SDS data items

ACTIONS

1. Analyze requirements for testability.
2. Develop System Testability Requirements.
3. Prepare Test Plan.
   - Establish approach and plan for system test.

Support Activities:

1. Update (as needed) TE data items
2. Support development of management plans and requirements.
3. Collect TE metrics data.
4. Conduct TE Trade Study.
5. Collect data for Lessons Learned.

DELIVERABLES

TE SDS Data Items:

Update during phase (as needed

1. Test Engineering Management Plan

Emphasis during phase

2. System Testability Requirements
3. Test Plan
   - System Test Plan
     - approach & plan

TE Reports:

1. Metrics Report
2. Lessons Learned
3. Trade Studies

REVIEW

1. Have the system requirements been examined for correctness, testability, and ability to be tested?
2. Are the Test and Integration Requirements complete?
3. Are the TE resources comensurate with the Test and Integration Requirements on the system.
4. Have testability requirements been incorporated into the System Requirements?
5. Has system test approach, plan, and design been established?
6. Have test responsibilities been established?

METRICS

1. Cost to uncover anomalies during the Requirements Phase versus total test cost.
2. Cost to develop each TE plan divided by defects or errors detected.
3. Cost of updating each test document due to changes in the system development documentation.

Figure 7. Requirements Phase-Action Chart

2.3.1 Requirements-Phase Objectives

TE objectives (see Figure 7) during the Requirements Phase are to:

- analyze the requirements for testability;
- define system testability requirements;
- document the system test approach and plan.

The importance of system specifications cannot be overstated. It is not possible to perform any aspect of testing without a set of testable requirements, specifications, and acceptance criteria. Therefore, requirements must be stated in sufficient detail to facilitate measurement and must include acceptance criteria for each individual requirement and for system requirements as a whole (see examples below). Each requirement should also be classified or grouped in terms of importance to overall system acceptability. Early involvement of TE in preparation of requirements, in order to ensure testability, is critical to project success.

The following illustrates how two unrelated requirements (n and n+1) can affect system testing in different ways, depending upon the acceptance criteria. Questions such as, "What test will be run?" "How many test cases are necessary?" and "What TE resources are needed?" must be addressed. Acceptance criteria help TE answer these questions. The acceptance criteria specify functional and performance tests that must be performed and the standards that need to be applied.

Requirements

n The car shall be able to accelerate from 0 to 60 miles per hour in less than 10 seconds.

n+1 The car shall have four windows that operate up and down.

Example: 1

Acceptance Criteria

1. The car shall be demonstrated to accelerate from 0 to 60 miles per hour with:
   - all windows simultaneously in the down position.
   - all windows simultaneously in the up position.

Test Engineering Impact

The acceptance criteria are only concerned with the two test cases where all windows are either up or down.

- At a minimum, two test cases are needed.
- Two testers are needed, one to operate the vehicle and one to take measurements.

Example: 2

Acceptance Criteria

1. The car shall be demonstrated to accelerate from 0 to 60 miles per hour with:
   - each window individually in the down position while the remaining windows are in the up position.
   - all windows simultaneously in the up position.
   - all windows simultaneously in the down position.

Test Engineering Impact

The acceptance criteria in this case are more stringent; they now address a new requirement that a combination of test scenarios be completed. This one acceptance criterion extends the time needed to complete the test, due to additional test cases. Therefore, the cost of testing also increases.

- At a minimum, six test cases are needed.
- Two testers are needed, one to operate the vehicle and one to take measurements.

Example: 3

Acceptance Criteria

1. The car shall be demonstrated to accelerate from 0 to 60 miles per hour with:
   - each window individually in the down position while the remaining windows are in the up position.
   - all windows simultaneously in the up position.
   - all windows simultaneously in the down position.
   - with each window being operated during acceleration.

Test Engineering Impact

The acceptance criteria are now very thorough and demanding, and therefore, increase once again the number of test cases needed. Also, a new wrinkle has been added: the need to add at least one extra tester to help operate the windows during test runs. This extra tester also brings up the question of whether this extra weight in the car conflicts with other requirements (e.g., maximum operating weight under acceleration). These more demanding acceptance criteria again increase the cost from previous examples.

- At a minimum, seven test cases are needed.
- At least three testers are needed, one to operate the vehicle, one to take measurements, and one or more additional testers to operate windows during the test.

During the Requirements Phase, critical system decisions are made. These become the basis for system design, which defines the final implemented system. It is imperative that TE be involved at this time, since any errors or defects not discovered in this phase will propagate down into design and implementation. It has been shown in many different studies that it is far less costly to discover and correct problems early on (e.g., the Requirements Phase) than it is to wait until later phases. It is an objective of TE during the Requirements Phase to ensure system requirements and test requirements are examined for testability. It is the responsibility of the System Engineering discipline to generate System Requirements and Test Requirements. However, TE, due to its expertise in test requirements, should be depended upon to supply inputs to these documents.

TE is interested in "testable" and the "ability to be tested" issues of system requirements. As stated earlier, "testable" means that a requirement is neither too

general in the way it is stated nor ambiguous as to what is to be tested (e.g., "the system shall be user friendly" is not testable). A requirement that is "unable to be tested" is one that is physically or economically impossible to test (e.g., a spacecraft larger than an environmental simulator, is unable to be environmentally tested).

System testability requirements are defined by TE. They are imposed by TE on systems for the purpose of facilitating the system integration and system test process. An example of such a requirement is, "The equipment shall have removable covers to allow collection of voltage measurements."

2.3.2 Requirements Phase Actions

System requirements and test requirements are examined by TE to determine that each requirement is properly stated, correctly interpreted, and reasonable when measured against good practices. System requirements and acceptance criteria should be clear, precise, unambiguous, and testable.

A System Testability Requirements data item is prepared to state test requirements imposed on the system by TE. This includes requirements for special hardware or software needed to either perform, maximize the quality of, or provide cost containment, (stay within the project-allocated Test Engineering budget) of the test process.

Once system requirements have been developed, preparation of the STP portion of the Test Plan begins. Technical test strategy is defined along with types of tests (e.g., system functionality, system performance, etc.). It may state what test facilities, test techniques, standards, personnel training, and tools will be used. TE resources, such as organization, budget, staffing, and schedule, are identified in this plan. It is important to remember that the STP is a technical document and should not be confused with the TEMP, which is a management document. The information in the STP and TEMP are intended for different audiences.

In conjunction with the STP, a Trade Study may be required to determine the best approach to testing based on resource constraints levied on TE by System Management. The TEMP should also be updated to reflect any changes in scope brought about by the maturing of requirements.

2.3.3 Requirements-Phase Receivables

Detailed Phase Plan

The Detailed Phase Plan is updated by System Management at the end of Phase 1, the Planning Phase, and then is given to the system development team at entry to Phase 2, the Requirements Phase. The Detailed Phase Plan is intended to establish readiness to begin the phase. More importantly, it also provides detailed schedules and precedence charts for intraphase products and actions for this phase.

Test Requirements

The Test Requirements, which are defined by System Engineering, consist of three components:

- Integration and Test Requirements
- Installation Test Requirements
- Operational Certification Requirements.

The above three components refer to the specific acceptance criteria for each of the final three life-cycle phases, respectively. Test requirements are used by TE as the criteria to determine:

- what types or groupings of tests are required;
- what test environments are required;
- how much testing is sufficient for system certification.

Test Requirements should also contain (if not contained explicitly in the System Requirements):

- Requirements in which nominal values can be attributed to measurable variables such as rate, frequency, speed, levels, or ratios. Accuracies, timing, and overall performance profiles for each of the minor functional capabilities are ascertained for future testing. These should be compatible with System Requirements and refined as necessary.
    - Requirements in which desired quality attributes of system products are defined. Quality attributes include:

reliability, integrity, usability/operability, maintainability, testability, portability/reusability, and interoperability.

System Requirements

System Requirements describe and define the system in terms of inputs, processes, and outputs. Functional requirements are detailed, formal specifications for every system capability specified by the user. These requirements must be testable, consistent, unambiguous, and traceable to their sources. They also should contain an analysis that:

- identifies each critical capability and interface;
- isolates functional execution and sequences;
- establishes major models used (e.g., mathematical or algorithmic);
- characterizes major data, peripheral, or processing interfaces supported.

Examples of Untestable Requirements Made Testable

Example: 1

"The system should be fast."

This requirement is vague, subjective, has no "shall" statement, and is unquantified.

"The system shall accelerate quickly."

Better, but the requirement is still vague, subjective, and unquantified.

A much better requirement that is specific, objective, and quantified:

"Under normal highway conditions (as defined in section 4.5), the system shall be able to accelerate from 0 miles to 60 miles per hour in 10 seconds."

Example: 2

"The system shall be reliable."

The requirement is vague, subjective, and unquantified.

"The system shall have a reliability factor of 0.9 and a mean time between failure of 6 years."

Better, but now there are two requirements, linked by the conjunction "and," in one statement. Consequently, this requirement is difficult to trace.

A much better requirement is:

"The system shall have a reliability factor of 0.9 as defined in John Musa's reliability model (section 4.2).

Under normal driving conditions (as defined in section 4.6), the system shall have a mean distance between failure of 60,000 miles."

Example: 3

"The system shall be wind tunnel tested."

There is no constraint on size, and, therefore, potential exists for an untestable system (in this case, it would be economically untestable, since a larger wind tunnel would need to be built).

A much better requirement is:

"The system shall fit into the wind tunnel located at 123 Main Avenue."

System Development Management Plan Updates

The System Development Management Plan, if updated since the last phase, is reviewed for impact on TE. If required, updates to TE documentation are completed.

2.3.4 Requirements-Phase Deliverables

System Testability Requirements (STR)

The STR (see Appendix C) define system requirements and system interface requirements imposed by TE, the essential contents are shown in Figure 8.

Examples of categories of system testability requirements that might be addressed are:

- Test facilities
- Test instruments
- Test sites
- Test data generators
- Test software

- System requirements for testability
- System interface requirements for testability

Figure 8. STR Essential Contents

Test Plan

The Test Plan (see Appendix D and, for examples, Appendices Y and Z) may be divided into a STP and a SITP. The Test Plan establishes the test approach and plan, test design, test cases and procedures, and test report for the integration and test of the system.

The hierarchical relationship of the STP and SITP to other TE documentation is shown in Figure 9. The STP and SITP, depending on the size and complexity of a system, can either be packaged as two documents of equal importance or one document covering both subjects. The important point is that the essential contents (see Figure 10) be addressed. The D-5000 System Development Guide does not require that a separate TEMP, STP, or SITP be written. It does provide guidelines to essential contents of these documents. A project- or task-specific document tree should have already been established during the Planning Phase.

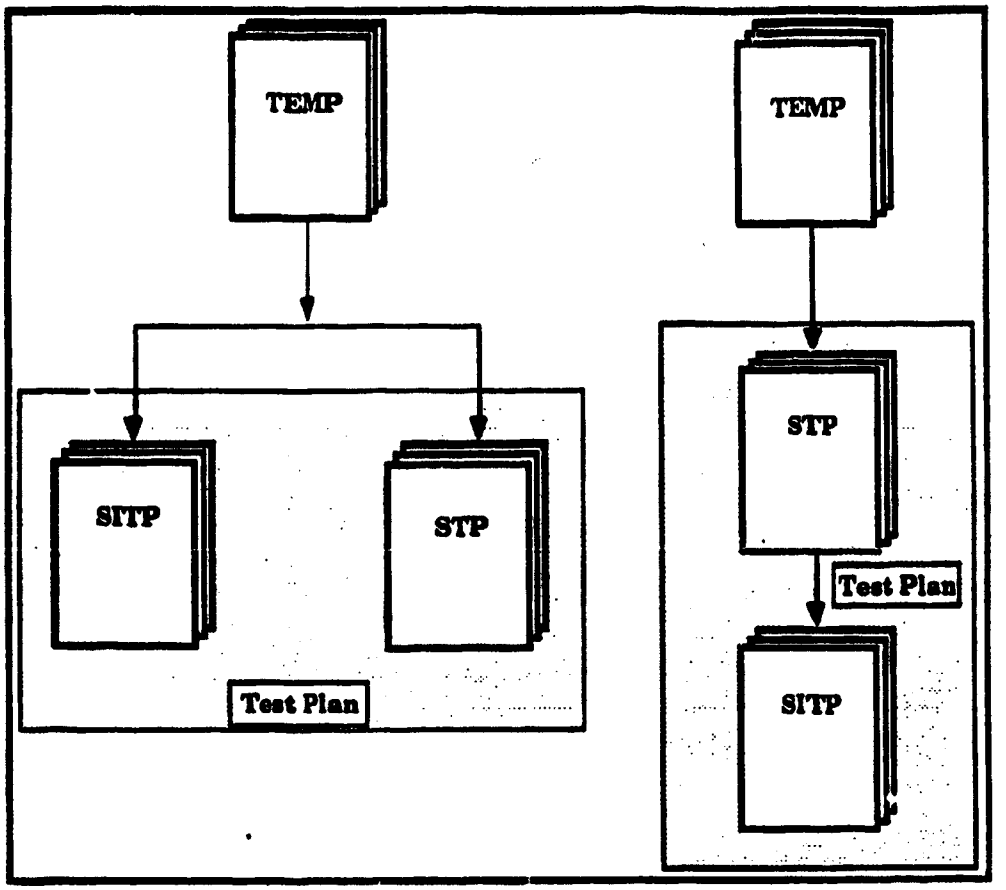

Figure 9. TE Test Plan Hierarchy

- System Test Plan
  - Test Approach and Plan
  - Test Design
  - Test Cases and Procedures
  - Test Report
- System Integration Test Plan
  - Test Approach and Plan
  - Test Design
  - Test Cases and Procedures
  - Test Report

Figure 10. Test Plan Essential Content

NOTE

D-5000 specifies the types of information needed by a test effort, but does not impose any constraints upon how information is assembled. Packaging of products is determined by a particular project or task.

Update TEMP

During this phase, the TEMP is updated, as required, to reflect changes made to the maturing requirements.

Collect Lessons Learned and Trade Study Data

As more data are collected for the TE Lessons Learned and Trade Study, the data should be merged or appended to that data already collected during the previous phase.

2.3.5 Requirements-Phase Metrics

Typical metrics are:

- cost of requirements testing (for analyzing whether a requirement is testable and able to be tested) divided by total cost of testing, used to discover defects;
- cost to prepare testing documentation versus total cost of testing;
- cost of individual TE plans divided by defects and/or errors detected by TE during the phase;
- cost of updating TE documentation due to changes (ripple effect) in system development documentation.

2.3.6 Requirements-Phase Review Criteria

Criteria used to obtain a base TE's recommendation to go to the next phase are as follows:

- all requirements have been examined for completeness and testability;

- all requirements can be tested with available technology and resources;
- all system testability requirements have been identified and incorporated into system requirements;
- the technical approach and plan for system testing have been approved.

2.4 Design Phase

OBJECTIVES

1. Develop System Test Plan:
   - Constitute/lead team of subsystem test representatives.
   - Develop and evaluate alternative test plans.
2. Develop test support system design.

RECEIVABLES

at the start of or during the phase

SDS Data Items:

1. System Design
2. Detailed Phase Plan
3. Updates to SDS data items

ACTIONS

1. Analyze system design for testability.
2. Prepare Test Plan.
   - System Test Plan.
     - Establish system test design.
   - System Integration & Test Plan.
     - Define integration test approach & plan.

Support Activities:

1. Update (as necessary) TE data items.
2. Support development of management plans and requirements.
3. Collect TE metrics data.
4. Conduct TE Trade Study.
5. Collect data for Lessons Learned

REVIEW

1. Is system design testable?
2. Are TE resources compatible with the system design?
3. Has the system integration and test organizational responsibilities been approved?
4. Has the System Test Plan, test design been identified and documented?
5. Has the System Integration Test Plan, test approach, plan, and metrics been defined?

DELIVERABLES

TE SDS Data Items:

Updated during phase (as needed)

1. Test Engineering Management Plan
2. System Testability Requirements
3. Test Plan
   - System Test Plan
     - Approach & Plan

Emphasis during phase

3. Test Plan
   - System Test Plan
     - Design
   - System Integration Test Plan
     - Approach & plan

TE Reports:

1. Metrics Report
2. Lessons Learned
3. Trade Studies

METRICS

1. Cost of testing to date divided by number of defects (errors/problems) found by TE in design validation. This is a measurement of the cost effectiveness of TE early participation in the test process.

Figure 11. Design Phase-Action Chart

2.4.1 Design-Phase Objectives

An objective of TE during the Design Phase (see Figure 11) is to examine system design for testability. As it does with requirements, TE focuses during design on measurability, traceability, accuracy, and completeness of design.

Another objective during this phase is to develop the System Test Plan, test design and to establish an approach and plan for system integration testing.

2.4.2 Design-Phase Actions

TE participates in the system design process. A TE perspective during design activities assists in filtering errors and ensures that a more testable system of higher quality will result. The system design is examined for testability with quantifiable methods of measurement, for correctness, and for traceability to requirements.

The Design Phase can be thought of as a funnel that takes system requirements and transforms them into design specifications. TE involvement during the Design Phase enhances effective testing. If a system requirement cannot be tested because of subsystem or system design, discovering and correcting this error during this phase is exponentially less costly than discovering it after implementation has started. Analysis by TE is directed at specific design concerns rather than broad-based testing. This enables the test process to be more productive and to develop more meaningful findings and recommendations. For example, a test engineer might examine a design specified in a program design language or participate in design inspections to ensure testability of design.

As the design is evolving, a system integration test approach and plan is developed. This approach and plan addresses:

- the types of integration testing necessary and possible with available resources allocated to integration testing;
- the kinds of tools, techniques, standards, methodologies, and training to be used to implement system integration testing;
- the necessary test environment for validation and verification of integration;
- the types of system integration test metrics necessary;

- the type of support required from other disciplines at the system level, and from Test Engineering at the subsystem level, to facilitate and coordinate necessary integration-related activities.

As an on-going activity from the Requirements Phase, system testing is refined.

Any changes to system development documentation that impact testing are reflected by updating the appropriate test documentation. Furthermore, all changes should be analyzed to ensure that test resources are still commensurate with planned activities. If a change has a significant impact on the test program, negotiation with System Management and the disciplines originating the change occurs and the resolution is documented.

Any alternative test strategies and approaches are documented in a Test Engineering Trade Study Report. This report is also a useful repository and future reference for options to be considered prior to changing a strategy or approach due to changes in development. Test metrics collected for this phase are analyzed, and a report is generated. The TEMP should also be updated to reflect any changes in scope brought about due to the maturing of requirements.

2.4.3 Design-Phase Receivables

Detailed Phase Plan

The Detailed Phase Plan for Phase 3, the Design Phase, is a receivable that is updated by system management at the end of Phase 2, the Requirements Phase, and presented at Phase 3 entry. The Detailed Phase Plan is intended to establish the readiness to begin Phase 3. More importantly, it also provides detailed schedules and precedence charts for intraphase products and actions. Since many test products are dependent on information provided by other disciplines, a baseline of these external discipline products is essential for TE to do its task. The alternative is the possibility of incorrect or inaccurate assumptions.

System Design

System Design defines how a system is to be functionally decomposed to facilitate development and operations, maps system requirements into system design, and defines what the subsystems are to be and do.

A System Design is needed before a SITP approach and plan can be completed. Since integration is the putting together of system components, an

effective integration test approach and plan depends on knowing what these parts are and how they are required to interact.

Updates to SDS Data Items

Test Engineering also requires any updates from other disciplines that impact testing.

2.4.4 Design-Phase Deliverables

Test Plan

An SITP (see Appendix D and, for examples, Appendices Y and Z) documenting the system integration test approach and plan is baselined by the end of this phase. This plan covers integration test activities and resources necessary to perform these activities.

The System Test Plan *design* is also baselined at the end of the design phase.

Since system testing addresses, "Did we build the right system?" rather than "Did we build the system right?" test cases can be defined once requirements are baselined. Furthermore, test procedures can be started in this phase as soon as a detailed System Design is specified and baselined. Final test cases and procedures will be derived during the Implementation Phase.

Updated TE Data Items

Update, as necessary, the TEMP and STP to reflect any changes to and assumptions about the evolving system. Note that these are updates to the work baselined in the previous phases and are different from the new work being done during the Design Phase. For example, the Test Plan work being done during the Design Phase is different from that done during the Requirements Phase.

2.4.5 Design-Phase Metrics

Design Phase Metrics include the cost of testing to date divided by number of defects (errors) found by TE in requirements and design analyses.

2.4.6 Design-Phase Review Criteria

The review criteria for the Design Phase are the following:

- TE has examined System Design for correctness and testability.
- TE has documented any discrepancies found (system problem reports). Resolution of problems should be agreed upon prior to entry into the Implementation Phase. Resolution can be achieved either by a solution arrived at through correction and/or compromise or by carrying a problem as a lien into the next phase.
- TE has updated the STP with test cases and test procedures. The SITP also must define TE responsibilities, resources, approach, and metrics.

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2.5 Implementation Phase

OBJECTIVES

1. Implement test support system and demonstrate its readiness.
   - HW/SW/facilities.
   - Staffing/training/procedures.
2. Coordinate and review subsystem test engineering.
3. Update Test Plan as necessary.

RECEIVABLES

at the start of or during the phase

SDS Data Items:

1. Implementation Plan
2. User Guide
3. Operator Manual
4. Detailed Phase Plan
5. Updates to SDS data items

ACTIONS

1. Examine the system implementation for testability.
2. Ensure that all preparations for system integration and system test are complete.
3. Review and coordinate TE subsystem Integration and Test Phase.
4. Complete development of Test Plan.
   - Complete System Test Plan.
     - Define test cases and procedures.
   - Complete System Integration Test Plan.
     - Define system integration test design.
     - Develop test cases & procedures.

Support Activities:

1. Update (as necessary) TE data items.
2. Support development of management plans and requirements.
3. Collect TE metrics data.
4. Conclude TE Trade Study.
5. Collect data for Lessons Learned

DELIVERABLES

TE SDS Data Items:

Updated during phase (as needed)

1. Test Engineering Management Plan
2. System Testability Requirements
3. Test Plan
   - System Test Plan
     - Approach & Plan
     - Design
   - System Integration & Test
     - Approach & Plan

Emphasis during phase

3. Test Plan
   - System Test Plan
     - Test cases & procedures
   - System Integration Test Plan
     - Design
     - Test cases & procedures

TE Reports:

1. Metrics Report
2. Lessons Learned
3. Trade Studies

REVIEW

1. Has the Implementation Plan been compared for consistency and testability with the Test Requirements?
2. Is the Test Plan complete and ready for entry into the Integration and Test Phase?
3. Are the TE staff and documentation in place and prepared for the Integration and Test Phase?

METRICS

1. TBD

Figure 12. Implementation Phase-Action Chart

2.5.1 Implementation-Phase Objectives

The objective during the Implementation Phase (see Figure 12) is to assess consistency of implementation with design and requirements. Completion of the STP and SITP occurs in this phase. The TE support system (test hardware, test software, test facilities, and staffing) should be in place at the end of this phase.

System implementation should be examined for testability and correctness. The probability for a successful Implementation Phase is partially dependent upon how thorough testing was in the Design Phase. Well-defined and measurable design specifications greatly simplify the implementation task. Failure to make decisions during early phases necessitates that these decisions be made during the Implementation Phase. Unfortunately, if not made earlier, these decisions may be reached at the wrong time and by the wrong individuals.

2.5.2 Implementation-Phase Actions

TE participates in examining a system implementation for testability, correctness, traceability, and completeness. This is a progressive activity for filtering errors at every stage of development. One method of analyzing the consistency of implementation with design and requirements is to use verification matrices that provide a trace of implementation to design and requirements. Furthermore, verification matrices make visible non-implemented or extraneous characteristics of the implementation, design, or requirements.

Once a system implementation is defined, the system and integration test cases and procedures can be completed. All test preparations, including detailed test plans, staffing, resources (hardware/software/facilities) should be ready at the end of this phase.

Collection of metrics and generation of reports, as defined in a TEMP, should continue. Alternative test strategies and approaches are documented in a TE Trade Study Report. This report is archived for future reference.

All system documentation, including updates, is reviewed for impact on TE, and all TE documentation should be updated as necessary to reflect any changes (e.g., problem resolutions and new assumptions).

2.5.3 Implementation-Phase Receivables

Detailed Phase Plan

Prepared by System Management the Detailed Phase Plan, for the Implementation Phase is a receivable that is updated at the end of the previous phase and then presented at phase entry. The Detailed Phase Plan is intended to establish readiness to begin the phase. More importantly, it also provides detailed schedules and precedence charts for intraphase products and actions.

System Implementation Plan

A System Implementation Plan, prepared by System Engineering, is required prior to defining system and integration test cases and procedures. The System Implementation Plan should describe the contents of system or subsystem builds or deliveries and the order in which they will be delivered. TE should be a participant in defining a System Implementation Plan, because any changes or decisions will significantly impact the test program development and structure.

System Operator's Manual and User's Guide

A System Operator's Manual and User's Guide is used for development of detailed system integration test and system test procedures. These two documents provide the expected system inputs and responses needed to write accurate detailed test cases and procedures.

The System Operator's Manual and User's Guide are the end user's sources of information for the system operational procedures, recovery strategies, and general characteristics. These documents also must be tested themselves for usability, accuracy, and correctness.

Updates to the System Development Documentation

Updates to system development documentation are reviewed for any possible impact on TE. Any updates to system documentation that affect TE, such as requirement changes that necessitate modification of test scope, strategy, or tests, must be negotiated with all disciplines involved. Resolution should be reflected in updates to TE documentation.

2.5.4 Implementation-Phase Deliverables

System Test Plan (STP)

The SITP (see Appendices E, F, and G for examples) sections to be developed in the Implementation Phase include test cases and test procedures.

System Integration Test Plan (SITP)

The SITP (see Appendices E, F, and G for examples) sections to be developed in the Implementation Phase include overall test structure, individual test classes, test cases, and test procedures.

Update Test Engineering Documentation

The TEMP, STP. and SITP, including detailed test procedures, should reflect the current state-of-readiness to conduct testing.

2.5.5 Implementation-Phase Metrics

- TBD

2.5.6 Implementation-Phase Review Criteria

Factors to consider prior to exiting the Implementation Phase are:

- degree of confidence in testability of the implemented system;
- consistency and compatibility of the System Implementation Plan with Test Requirements;
- completion and readiness of the System Operator Manual and User Guide for entry into the Integration and Test Phase;
- completion and readiness of the Test Plans for entry into the Integration and Test Phase;
- readiness of TE resources required for Phase 5, the Integration and Test Phase.

2.6 Integration and Test Phase

OBJECTIVES

1. Perform integration & test.
   - Execute integration & test procedures.
   - Operate & maintain test system.
   - Report/document results/liens.
2. Coordinate and review subsystem TE still in progress.
3. Update Test Plan as necessary.

RECEIVABLES

at the start of or during the phase

SDS Data Items:

1. Problem Reports
2. System Change Requests
3. Detailed Phase Plan
4. Updates to SDS data items

ACTIONS

1. Conduct system integration and system test.
   - Collect TE metrics and prepare report.
   - Write System Problem Reports (SPR).
   - Prepare System Integration Test Report.
   - Perform system regression testing as needed.
2. Conduct system test.
   - Collect TE metrics and prepare report.
   - Write System Problem Reports (SPR).
   - Prepare System Test Reports.
   - Perform system regression testing as needed.
3. Review and coordinate subsystem TE activities
4. Correlate test results to test requirements.

Support Activities:

1. Update (as necessary) TE data items.
2. Support development of management plans and requirements.
3. Collect TE metrics data.
4. Collect data for Lessons Learned

DELIVERABLES

TE SDS Data Items:

Updated during phase (as needed)

1. Test Engineering Management Plan
2. System Testability Requirements
3. Test Plan
   - System Test Plan
   - System Integration Test Plan

Emphasis during phase

4. System Test Report
5. System Integration & Test Report

TE Reports:

1. Metrics Report
2. Lessons Learned
3. System Problem Reports

REVIEW

1. Has the system met the Integration and Test Requirements for Phase 5?
2. Have all detected system problems been resolved (corrected or carried as a lien)?
3. Has all necessary regression testing been completed?
4. Have all outstanding problems been documented?

METRICS

1. TBD

Figure 13. Integration and Test Phase-Action Chart

2.6.1 Integration and Test Phase Objectives

Primary objectives of the Integration Phase (see Figure 13) are to integrate subsystems into a testable system and to conduct system integration testing and system testing.

2.6.2 Integration and Test Phase Actions

It is during integration testing that the internal interfaces and .he flow of information through a system, as built, are verified. At the system level, support of subsystem testing is necessary to more easily integrate a system. Often subsystem testing can be leveraged at the system level to optimize resources. Influence on subsystem testing allows higher leverage of subsystem tests at the system level, because some system integration and system tests can, for example, be conducted by combining or linking various subsystem tests. Consequently, TE needs to examine and to be cognizant of subsystem testing to ensure any requirements levied on subsystem testing that impact testing at the system level have been met. Subsystems, which have been integrated to create the system, are conducting installation testing at their levels and should be supporting testing at the system level when required. In addition, TE needs to support subsystem testing not only for easier system integration, but also for understanding the behavior and idiosyncrasies of the system.

TE needs to support system builds so that appropriate tests are conducted in the right order. Incremental or phased development increases the complexity of a test program significantly, because coordination of activities among an entire development team is essential. Therefore, due to the significant impact upon the test program, TE needs to be wary of any change in the order of delivery or method of incremental development. Typically, system integration testing and system testing is tightly coupled and interwoven to accommodate numerous partial deliveries. Regression testing, the selective retesting to detect faults introduced during modification of a system, also plays a more significant role for multiple version deliveries. This is because functionality verified in prior builds needs to be reverified to ensure that no unexpected changes (e.g., functions that no longer work, undocumented or approved changes, etc.) have occurred since the last delivery.

During this phase, actual tests are performed for system integration testing and system testing, as stated in detailed test procedures. Results from these tests should be logged and reported in System Integration Test Reports and System Test Reports, respectively. Anomalies and problems should be documented not only in test reports, but in System Problem Reports as well, since System Problem Reports highlight items for easier manageability. Information from results of testing as well as from initial planning is collected for a Lessons Learned Report.

Updates to the system development documentation are reviewed for any impacts on TE and test documentation is updated and changed accordingly. TE metrics continue to be collected and reported, as stated in the TEMP.

2.6.3 Integration and Test Phase Receivables

System and subsystem products (e.g., the implemented system, user documentation, etc.) are required before actual system integration and system testing can occur. Furthermore, system and subsystem products should be delivered as stated in the Configuration Management Plan and the System Implementation Plan.

Detailed Phase Plan

The Detailed Phase Plan for the Integration and Test Phase is a receivable that is updated by System Management at the end of the previous phase and then presented at phase entry. The Detailed Phase Plan is intended to establish readiness to begin the phase. More importantly, it also provides detailed schedules and precedence charts for intraphase products and actions.

Subsystem Anomaly Reports

Subsystem Anomaly Reports, written during subsystem testing, should be reviewed to factor in idiosyncrasies and to assess any changes to integration and/or testing at the system level.

Updates to System Development Documentation

Updates to system development documentation are reviewed for any possible impact on TE. Any updates to system documentation that affect TE, such as requirements changes that necessitate modification of test scope, strategy, or tests, are negotiated between involved parties. Resolutions must be reflected in updates to TE documentation.

2.6.4 Integration and Test Phase Deliverables

Test Reports

Test Reports (i.e, System Integration Test Report and System Test Report) of testing performed in the Integration and Test Phase, including history and analysis of results, are produced. Updates that reflect any changes, resolutions, or assumptions, to test documentation are provided.

System Problem Reports

Anomalies and problems found during testing should be documented in System Problem Reports to ensure a quick response and to provide management visibility.

Lessons Learned Report

Information learned during this phase and previous phases that can be used to improve the testing process in new or follow-on projects is collected in a Lessons Learned Report.

Update Test Engineering Documentation

The TEMP, STP, and SITP, including test history and reports to date, should reflect the current state-of-readiness to conduct testing during Phase 6, the Installation Phase.

2.6.5 Integration and Test Phase Metrics

- TBD

2.6.6 Integration and Test Phase Review Criteria

Prior to exiting the Integration and Test Phase, the following factors should be examined to accurately assess system readiness to enter the Installation Phase and to ensure that:

- there is confidence that system integration meets system test requirements;
- each system integration test has met the system test requirements;
- each system test has met the system test requirement;
- system problems found to date have been resolved, corrected, or carried as a lien;
- all necessary regression testing has been completed;
- all outstanding problems have been documented.

2.7 Installation Phase

OBJECTIVES

1. Perform system installation test.
   - Integrate & test system with peer systems.
   - Operate & maintain test system.
   - Report/document results/liens.
2. Coordinate and review subsystem TE still in progress.
3. Update Test Plan as necessary.

RECEIVABLES

at the start of or during the phase

SDS Data Items:

1. System Problem Reports
2. System Change Requests
3. Detailed Phase Plan
4. Updates to SDS data items

ACTIONS

1. Perform integration and test of system with peer systems.
   - Collect TE metrics and prepare report.
   - Document system problems found.
   - Update System integration Test Report.
2. Conduct system testing of installation.
   - Collect TE metrics and prepare report.
   - Document system problems found.
   - Update System Test Report.
   - Perform system regression testing.
3. Review and coordinate subsystem TE
4. Correlate test results to test requirements.

Support Activities:

1. Update (as necessary) TE data items.
2. Support development of management plans and requirements.
3. Collect TE metrics data.
4. Collect data for Lessons Learned.

DELIVERABLES

TE SDS Data Items:

Updated during phase (as needed)

1. Test Engineering Management Plan
2. System Testability Requirements
3. Test Plan
   - System Test Plan
   - System Integration & Test Plan

Emphasis during phase

4. System Test Report
5. System Integration & Test Report

TE Reports:

1. Metrics Report
2. Lessons Learned
3. System Problem Reports

REVIEW

1. Does the system meet the System Test Requirements for installation?
2. Have all detected system problems been resolved (corrected or carried as a lien)?
3. Have all unresolved problems been documented?

METRICS

1. TBD

Figure 14. Installation Phase-Action Chart

2.7.1 Installation-Phase Objectives

The objectives of the Installation Phase (see Figure 14) are to integrate and test the system in its operational environment, as specified in the STR.

2.7.2 Installation-Phase Actions

During the Installation Phase, the system is installed (or integrated) into an operational environment and again tested for any environment-caused deviations from the requirements.

Test Reports and System Problem Reports need to be generated after performing tests in this phase. Test reports should include not only a history of testing to date but also any TE recommendations based on analysis of test results. If any testing anomalies or significant observations about the test process occur during testing, the Lessons Learned Report should be updated.

As before, metrics and subsequent reports as specified in the TEMP should be collected and analyzed.

2.7.3 Installation-Phase Receivables

System and subsystem products for the Installation Phase, such as documentation and the system-as-built, are required before actual system integration and system testing during installation can occur. Furthermore, system and subsystem products should be delivered as stated in the System Implementation Plan.

Detailed Phase Plan

The Detailed Phase Plan for the Installation Phase is a receivable that is updated by System Management at the end of the previous phase and then presented at phase entry. The Detailed Phase Plan is intended to establish readiness to begin the phase. More importantly, it also provides detailed schedules and precedence charts for intraphase products and actions.

System and Subsystem Anomaly Reports

System and Subsystem Anomaly Reports should be reviewed to factor in idiosyncrasies and to assess any changes to integration and/or testing at the system level during installation.

Updates to System Development Documentation

Updates to system development documentation are reviewed for possible impact on TE. Any updates to system documentation that affect TE, such as requirement changes that necessitate modification of test scope, strategy, or tests, must be reflected in updates to TE documentation.

2.7.4 Installation-Phase Deliverables

Test Reports

Test Reports of testing performed in the Installation Phase, including history and analysis of results, are produced. Updates that reflect any changes, resolutions, or assumptions concerning test documentation are provided.

System Problem Reports

Anomalies and problems should be documented in System Problem Reports as documented in the Configuration Management Plan.

Lessons Learned Report

Information from results of testing as well as from initial planning is collected in a Lessons Learned Report.

Update Test Engineering Documentation

The TEMP, STP, and SITP, including test history and reports to date, should reflect the current state-of-readiness to conduct testing during the Operational Certification Phase.

2.7.5 Installation-Phase Metrics

TBD

2.7.6 Installation-Phase Review Criteria

Before exiting the Installation Phase, the following factors should be examined to assess readiness to enter the Installation Phase and to ensure that:

> there is confidence that the system has met System Test Requirements for installation;

the system has met the System Test Requirements in an operational or integrated environment;

all detected system problems to date have been resolved, corrected, or carried as a lien;

all unresolved problems have been documented.

2.8 Operational Certification Phase

OBJECTIVES

1. Perform system operations test.
   - Operations readiness testing.
   - Operate & maintain test system.
   - Report/document results/liens.
2. Coordinate and review subsystem TE activities still in progress.
3. Update Test Plan as necessary.

RECEIVABLES

at the start of or during the phase

SDS Data Items:

1. System Problem Reports
2. System Change Requests
3. Detailed Phase Plan
4. Updates to SDS data items

Other:

1. Installed and tested system

ACTIONS

1. Conduct operational certification of system.
   - Collect TE metrics and prepare report.
   - Document system problems found.
   - Update System Integration Test Report.
   - Update System Test Report.
2. Correlate test results to test requirements.

Support Activities:

1. Finalize (as necessary) TE data items.
2. Collect TE metrics data & finalize report.
3. Finalize Lessons Learned.

DELIVERABLES

TE SDS Data Items:

Finalize during phase (as needed)

1. Test Engineering Management Plan
2. System Testability Requirements
3. Test Plan
   - System Test Plan
     - System Test Report
   - System Integration & Test Plan
     - System Integration & Test Report

TE Reports:

1. Metrics Report
2. Lessons Learned
3. System Anomaly Reports

REVIEW

1. Does the system meet the System Test Requirements for operational certification?
2. Have all system problems found been resolved (corrected, carried as a lien, or waived)?
3. Have all remaining problems or liens been documented?
4. Have all necessary regression tests been completed and met the certification criteria?

METRICS

1. TBD

Figure 15. Operational Certification Phase-Action Chart

2.8.1 Operational Certification Phase Objectives

A major objective of TE in the Operational Certification Phase (see Figure 15) is to participate in conducting the tests that ensure that a system has met its Operational Certification Requirements.

2.8.2 Operational Certification Phase Actions

Testing during the Operational Certification Phase is conducted with a focus on operational readiness and the ability of a system to meet its Operational Certification Requirements. Based on results from these tests and assessment of risks from uncorrected and open liens, a decision is made whether a system is operational or not.

Final System Problem Reports, the System Test Report, and System Integration Test Report are produced. A final Lesson Learned Report is also generated as part of the TE history of this project.

Updates to the implemented system and system documentation are reviewed for any impact on TE, and TE documentation is changed accordingly in order to achieve consistency and to preserve project history.

2.8.3 Operational Certification Phase Receivables

Final system and subsystem products for the Operational Certification Phase, such as documentation and the as-built system, are required before actual testing during operational certification can occur. Furthermore, all system products should be delivered as stated in the System Implementation Plan.

Detailed Phase Plan

The Detailed Phase Plan for the Operational Certification Phase is a receivable that is updated at the end of previous phase by System Management and then presented at phase entry. The Detailed Phase Plan is intended to establish readiness to begin the phase. More importantly, it also provides detailed schedules and precedence charts for intraphase products and actions.

System and Subsystem Anomaly Reports

System and Subsystem Anomaly Reports should be reviewed to factor in idiosyncrasies and to assess any changes to integration and/or testing at the system level during operational certification.

Updates to System Development Documentation

Updates to system development documentation are reviewed for any possible impact on TE. Any updates to system documentation that affect TE, such as requirements changes that require modification of test scope, strategy, or tests, must be reflected in updates to TE documentation.

2.8.4 Operational Certification Phase Deliverables

Test Reports

Test Reports of testing performed in this phase, including history and analysis of results, are produced. Updates, that reflect any changes, resolutions, or assumptions, concerning actual testing are provided and finalized for archiving.

System Anomaly Reports

All new anomalies and problems should be documented in System Problem Reports for management visibility and then archived.

Lessons Learned Report

All information collected during the development life cycle, initial planning data, test documentation, and test results, are collected in the Lessons Learned Report and then archived.

Update Test Engineering Documentation

The TEMP, STP, and SITP, including test history and reports-to-date, should reflect actual activities and results, and then should be finalized for archiving.

2.8.5 Operational Certification Phase Metrics

TBD

2.8.6 Operational Certification Phase Review Criteria

Before a system is deemed operationally certified, it should be examined to ensure that:

there is confidence that the system meets System Test Requirements for certification;

all system problems found to date have been resolved, corrected, or carried as liens, and that all remaining problems or liens have been documented;

all necessary regression tests have been completed, and the system has met its Operational Certification Requirements.